BERNARD (C.)

Lectures on the physiology of the heart xxxxx

LECTURE

ON THE

PHYSIOLOGY OF THE HEART,

And its Connections with the Brain,

DELIVERED AT A MEETING AT THE SORBONNE, THE 27TH MARCH, 1865,

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ERRATA.

Page 15, 20th line—for *realised*, read *realized*.
Page 28, 10th line—for *bulba*, read *bulb*.
Page 32, 23d line—for *entrance towards*, read *commencement of*.
Page 33, 3d line in the description of Fig. 14—semi-colon (;) after pneumogastric.
Page 34, 16th line—semi-colon (;) after arrested.
Page 45, 6th line—comma (,) after souvenir.
In the description of the 2d Plate, *higher* should read *lighter*.

On the Physiology of the Heart and its Connections with the Brain.

GENTLEMEN:

I intend to entertain you in a general manner with the physiology of the heart, but will dwell more particularly upon those points which seem necessary to clear up the physiology of the heart of man.

To the physiologist the heart is the central organ of the circulation of the blood, and in this respect it is an organ essential to life. But by a singular privilege, enjoyed by no other organic apparatus, the word heart has passed, like the ideas one has of its functions, with very different acceptations, from the language of the physiologist into the language of the poet, the romancer and the man of the world. The heart may not only be a vital motor apparatus, pumping the sanguineous liquid into every part of our body, which it animates, it may also be the seat and symbol of the noblest and tenderest sentiments of our soul. The study of the human heart may be pursued not only by the physiologist, it may also serve as the basis of the conceptions of the philosopher and the inspirations of the poet and the artist.

The question now before us concerns the anatomical heart—that is to say, the heart studied from a physiological, scientific, and purely experimental point of view.

But will this rapid examination which we are about to make of the functions of the heart overthrow the ideas generally entertained respecting it? Ought physiology to dissipate the illusions, and show us that the sentimental *role* at all times attributed to the heart, is but a fiction purely arbitrary? In a word, shall we be obliged to acknowledge a complete and peremptory contradiction between science and art, between sentiment and reason? As to myself, I do not believe in the possibility of that contradiction. Truth cannot differ from itself, and the truth of the man of science will not be contradicted by the truth of the artist. I believe, on the contrary, that the science which flows from a pure source will become luminous to all, and that science and art should give their aid in explaining and interpreting for each other. I think, indeed, that in its elevated regions, human knowledge forms an atmosphere common to all cultivated intelligences, in which the man of the world, the artist and the *savant*, will, as a matter of course, meet and fully comprehend each other.

In that which follows, I will not attempt to deny, in the name of science, all that may be said, in the name of art, upon the heart considered as an organ intended to express our affections and sentiments. On the contrary, I would like to be able to confirm art by science, in trying to explain, by means of physiology, that which, until now, has been but a simple intuition of the mind. I know that I have undertaken a very difficult task, it may be one of temerity, because of the slight advance that is yet made in the science of the phenomena of life. However, the beauty of the subject, and the light that physiology already seems to shed upon it, determine and encourage me to the investigation. Be-

sides, in speaking here upon the physiology of the heart, it will not be necessary to go into the details of a complete experimental and analytical investigation; at this time, this would be impossible—it is only a simple test that I wish to make, and it will suffice me in expressing my physiological ideas to support them by the clearest and best ascertained facts in science.

The heart is truly a living motor machine, a forcing pump, intended to distribute to all of the organs of our body the nutritious fluid, the excitor of their functions. This mechanical *rôle* characterises the heart in an absolute manner, and wherever the heart exists, however simple it may be, or whatever complication it may present in the animal series, it constantly and necessarily performs this function of organic irrigator.

The anatomist regards the human heart as a *viscus*, that is, as one of the organs which forms a part of the apparatus of nutrition, situated in the splanchnic cavities. Everyone knows that the heart is placed in the thorax between the lungs—that it has the form of a cone, whose base is fixed by large blood vessels; whose point is free, inclining downwards to the left, in such a way as to place it between the fifth and sixth ribs below the left nipple. As to the nature of its tissue, the heart belongs to the muscular system; it is divided into cavities, which are reservoirs for the blood—this is the reason why anatomists still call it a hollow muscle. In the human heart are four compartments or cavities; two form the superior part, or the base of the heart, and are called the *auricles*—they receive the blood from all parts of the body, by means of large tubes, called *veins;* the other cavities form the lower portion, or apex of the heart: they are the *ventricles*, and are intended to force

the blood into all parts of the body, by means of large vessels, called arteries (Fig. 1).

Fig. 1.—Longitudinal section of the heart of man, showing its four cavities.

od.—Right auricle. *vd.*—Right ventricle. *og.*—Left auricle. *vg.*—Left ventricle. The arrows placed at the entrance of the different vessels terminating at the cavities of the heart, indicate the direction of the current of the blood in these vessels.

Each auricle communicates with the ventricle which is below it on the same side, but a longitudinal septum separates laterally the auricles and ventricles in such a way, that the human heart, which is really double, is divided into two simple hearts, each formed of one auricle and one ventricle, situated, one on the right and the other on the left of the middle septum. Each ventricular cavity is furnished with two *valves*. The one placed

where the blood passes from the auricle to the ventricle, is called the *auriculo ventricular* valve; the other, situated where the blood leaves the ventricle by the artery, is called the *sigmoid* valve.

The human heart, as well as that of mammals and birds, is anatomically, double, and composed of two single hearts, called the *right heart* and the *left heart*. Each of these hearts play a very different part in the economy (Fig. 2). The left heart, called the heart of red blood, is destined to receive into its auricle, by the pulmonary veins, the pure and lively red blood which comes from the lungs; this blood passes into its ventricle, which distributes it by the arteries to every part of the body, where it becomes impure and black. The right heart, called the heart of black blood, receives into its auricle, by the vena cava, the impure blood which comes from every part of the body, and passes it afterwards into its ventricle, to be distributed to the lungs, where it becomes pure and of a lively red color. In a word, the left heart presides over the distribution of the vital liquid to all of our organs, and to all of our tissues: and the right heart presides over the revivification of the blood in the lungs, to restore it to the left heart.

These premises being established, we shall consider the heart as an organ distributing life to all parts of our body, sending to them the nutritious liquid which is indispensible to their life, and the manifestation of their functions. As to the nutritious liquid itself, it is represented by the blood, which is identical in all vertebrated animals, whatever may be their diversity in the animal species, and the variety of their food.

In the external phenomenon of the mode of feeding, the zoologist distinguishes the ferocious carnivora, which

Fig. 2.—Intended to explain the mechanism of the circulation.

o.—Left auricle. *vg.*—Left ventricle. *o.*—right auricle. *vd.*—Right ventricle. The circulating system of red blood consists of arteries, over which the left heart presides—*oog.* is represented by the higher portion of the figure. The circulating system of dark blood consists of the veins over which the right heart presides—*ood.* is represented by the greyish tint. The arrows indicate the direction of the current of the different vessels. Above and below are seen the capillary network of the superior and inferior portions of the body, where the arterial blood is transformed into venous blood, and in the middle, the capillary network of the lungs, where the venous blood is revivified, to become arterial.

feed upon palpitating flesh, the peaceful ruminant, which lives upon the herbs of the field, the frugivora and gramenivora, which are nourished more particularly by fruits and grain; but when we descend into the intimate phenomenon of nutrition, general physiology teaches us that that which, properly speaking, is nourished in animals, is not the specific and individual type, which varies to infinity, but the elementary organs and tissues only, which are everywhere destroyed and live in the same manner. According to Gœthe, nature is a great artist. Animals are constituted of the same organic materials; it is the arrangement and relative disposition of these materials which determine the variety of forms and the specific animal properties of these truly organised monuments. In like manner in the monuments of men, the materials are alike in all of their physical properties, and however different their arrangement, the various ideas may be realized, and give rise either to a palace or a cottage. In one word, the specific type exists, but only in the state of an idea realised. Physiologically, it is not the animal type which lives and dies, but the organic materials or tissues which compose it; in the same way with the edifice which decays, it is not the ideal type of the monument which deteriorates, but only the stones of which it is built. We cannot, then, deduce from general physiology any essential difference in the organic nutrition, from the great variety of the food of animals. In man and all other animals, the elementary organs and living tissues are sanguinary; that is to say, they feed upon the blood in which they are immersed. They live there, as aquatic animals live in water, and in the same way that it becomes necessary to renew the water which changes and

loses its nutritive elements, so it becomes necessary to renew, by means of the circulation, the blood which loses its oxygen and is charged with carbonic acid gas. This, then, is precisely the duty devolving upon the heart. The system of the left heart carries the blood to the organs which animate them; and the system of the right heart carries away the blood which has given them momentary life. When we wish to understand the functions of an organ physiologically, it is always necessary to trace the vital properties of the substance of which it is composed to their origin—it is consequently in the properties of the tissue of the heart that we will be able to find the explanation of its functions. No difficulty will be experienced in making this investigation, for as we have already said, the heart is a muscle possessing all of the physiological properties of that tissue. It will suffice, then, to call to your notice that this fleshy or muscular tissue consists of fibres which possess the property of contracting.

When the muscular fibres are disposed so as to form a long muscle, whose extremities are inserted into two bones, forming a joint, the necessary effect of the contraction or shortening of the fibre is to cause the two bones to move on each other, thus approximating; but when the muscular fibres are disposed so as to constitute the walls of a muscular pouch, as is the case in the heart, the necessary effect of the contraction of the muscular tissue is to shut up or to cause the cavity to disappear more or less completely, by expelling its contents. This enables us to understand how the blood is expelled in a direction determined by the disposition of the cardiac valves at each contraction of the cavities of the heart (Fig. 3).

FIG. 3.— Longitudinal section of the heart of man, to show the mechanism of the circulation in the different cavities.

od.—Right auricle. *vd*.—Right ventricle. *og*.—Left auricle. *vg*.—Left ventricle. The arrows placed at the opening of the different vessels terminating at the cavities of the heart, indicate the current of the blood in these vessels.

When the auricle contracts, the blood is sent into the ventricle, because the auriculo ventricular valve is relaxed; when the ventricle contracts, the blood is sent into the arteries, because the sigmoid, or arterial valves, are relaxed, to allow the blood to pass at the same time that the auriculo ventricular valve contracts, to prevent the blood from flowing back into the auricle. The contraction of the cavities of the heart which empties them is followed by a dilatation, during which they are again filled with blood, then by a new contraction which again empties them, and thus the circle is continued. It

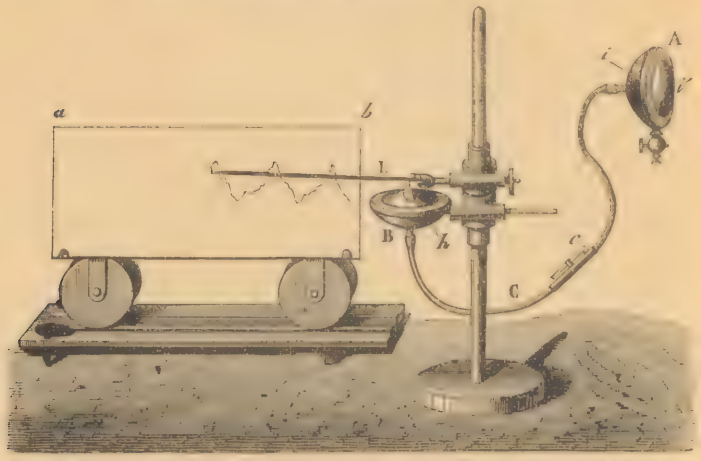
follows, that the motion of the heart consists of a succession of alternate movements of contraction and dilatation of these cavities. The contractile movement is called the *systole*: the *diastole* is the act of dilatation. The four cavities of the heart contract and dilate successively, two and two, first, the two auricles, then the two ventricles. A very short interval of repose separates the contraction of the auricles from the contraction of the ventricles; a little longer interval then succeeds the contraction of the ventricles. It would be entirely foreign to our subject to describe, in detail, the mechanism of the circulation in the different cavities of the heart. In our explanations further on, we shall have to take notice only of the function of the left ventricle, which, as we have already said, is the ventricle that supports, feeds and animates all the organs of the body. It will suffice us, then, to say, that at the moment of the contraction of this ventricle, the heart projects itself forward and strikes, like the beating of a clock, between the fifth and sixth ribs, below the left breast. This is called *the beating of the heart*. At the same moment of the contraction of the left ventricle, the blood is sent into the aorta, and by this channel, into all of the arteries of the body, with a pressure capable of supporting a column of mercury of about five inches in height. It is that which produces the disturbance observed in all of the arteries, and which is called the *pulse*.

All of the mechanical movements of the heart have been the object of laborious investigation, and modern science has studied the phenomena of the circulation by the aid of graphic processes, which give to these researches great exactness. The only point to which we will call your attention, is that the heart is a true living

machine, which acts like a forcing pump, in which the piston is replaced by the muscular contraction. The heart itself can trace upon paper each of its contractions with their slightest modifications, and it may then be said, without metaphor, that we read the human heart. Dr. Marey, to whom the Academy of Sciences has ordered a premium, this year, for his important works on the circulation of the blood, will give you an idea of these graphic means, by exhibiting before you experiments with the apparatus which he has invented, or brought to its present perfection (Fig. 4).

The cardiographic apparatus for the examination of the human heart, is composed of two parts—a stethescopic drum (A), intended to detect the beatings of the heart, and a registry drum (B), intended to write them off. The stethescopic drum (A) intended to receive the impulses, should be applied over the region of the heart: it is formed by a funnel, the broad portion of which is exactly closed by two membranes of caoutchouc (*i*, *i*) between which, water is introduced, so as to make them swell out in the form of a double convex. The registering drum (B) is formed by another funnel, the broadest part of which is closed by a single membrane of caoutchouc, on which rests a small lever (L), as light as a feather; these two funnels are connected by a tube of caoutchouc (C), which transmits the vibrations of the receiving drum (A) to the enregistering drum (B). Each pulsation of the heart reverberates against the water drum of the stethescopic funnel; the air behind these distended membranes vibrates—these vibrations are transmitted by means of the air which fills the caoutchouc tube, to the membrane of the registering drum, which, vibrating in its turn, causes the little lever to

FIG. 4.—Cardiographic or Sphygmographic Apparatus of Mr. Marey, for directly inscribing the pulsations of the heart.



A. Stethoscopic drum, which is placed on the chest, to detect the beatings of the heart. *i*, *i*. Two membranes of caoutchouc, protruding in opposite directions and having between them a lenticular cavity filled with water. B. Registering drum, covered by a caoutchouc membrane slightly protruding *h*, on which is a small prism, which supports the lever L. C. Caoutchouc tube, intended to transmit the vibrations of the receiving drum A, to the registering drum B. *c*. Valve, for regulating the quantity of air contained in the caoutchouc tube C. L. A very light lever, jointed at one of its extremities so as to move freely around in a vertical plane; it rests upon a small prism, fixed to the caoutchouc membrane *h*, of the registering membrane B, and is raised or lowered with it; its free extremity rests against the blackened paper *ab*. *ab*. Blackened tablet, moving regularly on a railway from *b* to *a*, and which receives the inscriptions of the motions of the lever L, representing the beatings of the heart.

move; its point writes, upon the moving paper, blackened with lamp-black, the pulsations of the heart. In this way is traced a figure written by the heart itself, and which permits us to read its most intimate functions. The *cardiograph* is an instrument so much the more delicate and correct as it can be more closely applied over the heart, and as it is the least separated by the walls of the chest. Without explanation, it

will readily appear, why it is more easy to read the heart of children than that of adults, and why, also, it is naturally more difficult to read the heart of women than that of men.

It is not my intention to initiate you into the interpretation of all of the cardiac writings in the normal and pathological state: I wish simply to exhibit to you a few tracings representing the beatings of the heart either in man or different animals, so as to give you an exact idea of what may be obtained by these graphic means.

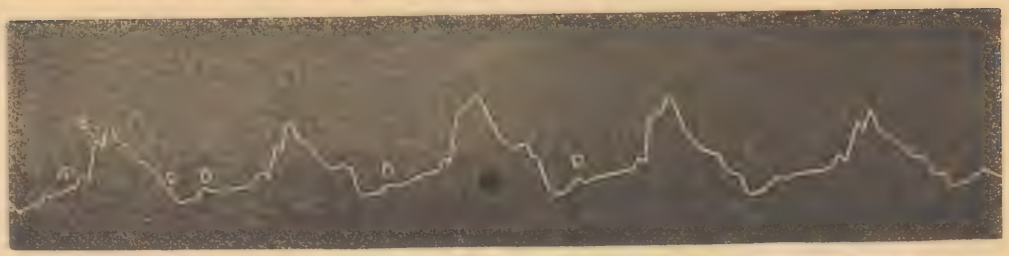
Here is traced the beatings or pulsations of the heart of a young man in the natural or normal state (Fig. 5).

Here is traced the pulsations of the heart of a rabbit (Fig. 6).

If we pass on now to cold-blooded animals, whose hearts are simple, we will see the tracings of the pulsations also simplified in a corresponding manner.*

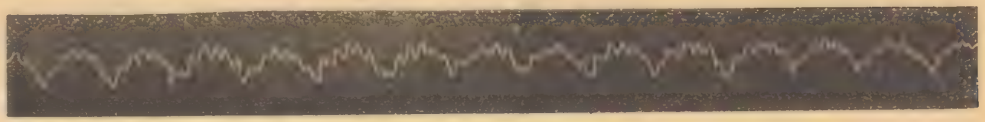
* To obtain a tracing of cold-blooded animals, the cardiographic instrument is simplified: it consists simply of an enregistering lever, which rests directly over the heart of the animal.

FIG. 5.—Tracings of the pulsations of the heart of a young man in the normal state.



A. Systole of the auricle. B. Beginning of the systole of the ventricle. C. End of the systole of the ventricle. D. Particular motion, due, perhaps, to the sudden arrest of the blood in the ventricle during its relaxation.

FIG. 6.—Tracings of the pulsation of the heart of a rabbit.



The tracing of the pulsations of the heart of a frog (Fig. 7).

FIG. 7.—Tracings of the pulsations of the heart of a frog.

A. Systole of the auricle. B. Systole of the ventricle.

FIG. 8. Tracings of the pulsation of the heart of an eel.

A. Systole of the auricle. B. Systole of the ventricle.

The tracing of the heart of an eel (Fig. 8).

The tracing of the heart of a tortoise (Fig. 9).

Fig. 9.—Tracings of the pulsations of the heart of a tortoise.

A. Systole of the auricle. B. C. Systole of the ventricle.

Fig. 10.—Tracings of the pulsations of the heart of a crab.

Lastly, is the tracing of the beatings of the heart of an invertebrate animal, a crab (Fig. 10).

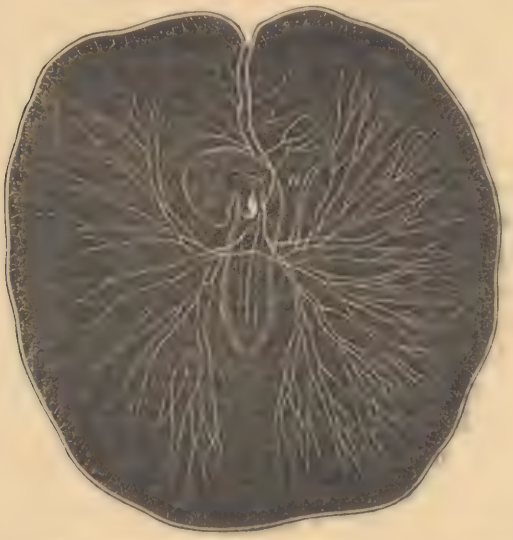
The question which we now wish to examine more particularly in this lecture, is how the heart, that simple motor of the circulation of the blood, can, by re-acting under the influence of the nervous system, co-operate with that exceedingly delicate mechanism of the sentiments which are produced in us.

The heart strikes us at once, as a strange organ, on account of its exceptional activity. In the development of the animal body, each vital organ enters upon the performance of its function, only after it has finished its evolution and acquired its definite texture. There are organs even, particularly those which are destined for the propagation of the species, which take no part in the organic scene until a long time after birth, they then disappear, to return again to a state of torpor during the last period of the life of the individual. The heart, on the contrary, manifests its activity from the beginning of life, long before it possesses its perfect form and its characteristic structure. This fact is not only remarkable in showing the precocity of the functions of the heart, but it is also of a nature to cause the physiologist to reflect deeply upon the real connection which may exist between anatomical forms, and the vital properties of the tissues.

Nothing is so beautiful as to watch the birth of the heart. In the chick, at the twenty-sixth or thirtieth hour of incubation, there appears upon the germinal plane (or field) a very minute point, the *punctum saliens*, upon which at last may be seen movements, at first unfrequent and hardly perceptible. These motions gradually become more decided, and more frequent; the heart is better defined; arteries and veins pierce it; the sanguineous liquid manifests itself more distinctly,

and a provisory vascular system (*area vasculosa*) is displayed, radiating around the heart, now physiologically constituted the organ of embryonic circulation (Fig. 11).

FIG. 11.—*Area vasculosa*, or germinal field, representing the primitive circulation of the chick in the egg.



a. Primitive heart, central apparatus of the circulation.

At this period, the fundamental lineaments of the body of the animal have already appeared: the heart, now in full activity, presents an isolated, moving blood point, anterior to the organization, and destined to transport on the highway of life, the materials necessary for the formation of the animal body.

While this organ is engaged in the construction and development of the whole body, its own volume is increased and developed. At its beginning, it was a small vesicle, obscurely contractile, like the circulatory vesicle

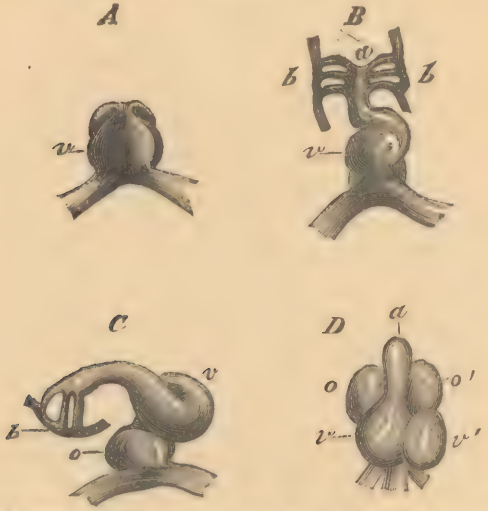
of an infusorial; but this vesicle soon lengthens itself, and beats with rapidity; the inferior portion receives the blood, and represents an auricle; the superior part constitutes a true ventricle, which sends the blood into the aortic bulb, dividing into the bronchial arcs—it is then the heart of a fish. After a while this heart undergoes a motion combined of a twist and see-saw action, which brings up the auricular part, and lowers the ventricular. Before the completion of this see-saw motion, the organ presents a heart with three cavities—it is now the heart of a reptile—and from the time this movement is completed, it possesses the four cavities of the heart of a bird or mammal. The various phases in the development of the heart, show us, then, that this organ does not reach the most perfect state of organization—as in birds, mammals and man—until it has passed through the forms which remain definite in the inferior classes (Fig. 12). It is the observation of these, and many other facts of the same kind, which has given birth to the idea, philosophically true, that every animal, in its embryonic condition, reflects the organizations which are inferior to it.*

The heart differs, also, from all the muscles of the body, in this: that it acts from its first appearance in the embryo, and before it is fully developed. Its organization once completed, it still continues to form an exception in the muscular system. Indeed, the whole muscu-

* It is true that the heart of a chicken, during its development, has three cavities, and possesses an interventricular septum, which does not exist in the adult reptile. We must then compare the heart of a chick, during development, with the heart of a reptile undergoing development; for it may be possible that this interventricular septum existed in the reptile at a certain period of development, and that it disappears after a while.

lar apparatus presents us with alternations of activity and repose; the heart, on the contrary, is never at rest; of all the organs of the body, it acts the longest; it

FIG. 12.—Successive periods of the development of the heart of a chick.



A. Primitive heart, formed of but one cavity. *v.* The arterial and the venous heart, not yet being distinct.

B. Second period of the development of the heart, corresponding to the heart of a fish. *v.* The arterial heart, making the auricular portion placed behind. *b. b.* The bronchial arteries emanating from the aortic bulba.

C. Same figure as the preceding, seen in profile. *v.* Arterial heart. *o.* Venous heart. *b.* Bronchial arcs.

D. Third period of the development of the heart, corresponding to the heart with the three cavities of reptiles. *v. v.* The two arterial hearts, right and left, corresponding to the two ventricles, right and left, of the fully developed heart. *o. o.* The two venous hearts, right and left, corresponding to the two auricles, the right and the left, of the fully developed heart. *a.* Aortic bulb.

exists before the organism, it survives it, and in the successive and natural death of the organs, it is the last to continue to manifest its functions. In a word, to use

the expression of the great Haller, the heart is the first to live (*primum vivens*) and the last to die (*ultimum moriens*). In that extinction of the life of the organism, the heart continues to act when the organs are silent around it. It is the last awake, as if it awaited the end of the struggle between life and death; for so long as it beats, life may be re-established; when the heart has ceased to beat, it is irrecoverably lost, and as its first pulsation was the certain sign of life, so its last pulsation is the certain sign of death.

The preceding notions are necessary, as they will assist us the better to comprehend the action of the nervous system over the heart. We have already perceived that this muscular organ possesses the property of contracting without the intervention of the nervous influence. It begins its functions long before the nervous system has given any sign of life: there is even more than this: the nerves may be well developed and anatomically constituted, yet without acting on any of the muscular organs which are already developed. Indeed, I have proved, by direct experiments, that the nervous extremities are not physiologically fused into the muscular system, except in the last stages of embryonic life. After birth, when the nervous system has assumed the control over all of the muscular organs of the body; the heart, nevertheless, passes from its control, to perform its functions of motor power over the central circulation. The muscles of the members of the body are paralysed by cutting the nerves which animate them: the movements of the heart are never paralysed by dividing the nerves which are spent upon its tissue, on the contrary, its movements become more rapid. Those poisons which destroy the properties of

the motor nerves, abolish the movements of all of the muscular organs of the body, whilst they exert no influence over the pulsations of the heart. We have here a frog poisoned with *curare*: this poison paralyses, *par excellence*, the motor nervous system: you see that the heart continues to beat, and causes the blood to circulate through the body of this animal, which is absolutely deprived of all motor nervous influence.

From all of this, shall we conclude that the heart possesses no nerves? This opinion, entertained by the older physiologists, is at this day contradicted by anatomy. That science shows us that the tissue of the heart is abundantly supplied with nerves (Fig. 13). It is not, then, to the absence of nerves that we are to attribute all of the anomilies that the heart presents; it depends upon a very particular mechanism of the nerves, which remains still to be examined. The well known reaction of the motor nerves on the muscles in general, resolves itself into this fundamental principle: so long as the nerve is not excited, the muscle remains in a state of relaxation and repose, but when the nerve becomes naturally or artificially excited, the muscle is thrown into action—contraction. The observation of the influence of our will over the movements of our limbs, will be sufficient to prove what I have advanced, but really nothing is more easy of demonstration, by direct experiments, made on living animals, or on those but recently dead (Fig. 13).

If a frog be prepared by vivisection, so as to insulate a nerve which is expended upon the muscles of a limb, we see, that so long as this nerve is not touched, the muscles of the limb remain relaxed and in repose, but as soon as the nerve is excited by pinching, or better still,

by passing a current of electricity through it, the muscles become energetically and rapidly contracted; here is a general fact, which may be experimentally proved

FIG. 13.—The heart, with the nervous branches which it receives from the brain.

C. The heart. *a.* The carotid artery going to the brain. *n.* Pneumogastric nerve, the branches of which are distributed to the heart.

in man, and all vertebrated animals, either during life or immediately after death, so long as the muscular and nervous systems preserve their respective vital properties.

If now, we act upon the nerves of the heart by analogous processes, we will see that this paradoxical muscular organ presents, in this point of view, an exception; and, to be more explicit, I will even say that it presents phenomena absolutely in opposition to those which we have observed in the muscles of the extremities. To be within the truth, it will suffice to reverse the terms of the proposition, and say, that so long as the nerves of the heart are not excited, it beats and remains in a functional state; but if the nerves are excited naturally or artificially, it becomes relaxed, and is reduced to a state of repose. If a frog, or any other animal, either living or recently dead, is prepared, by vivisection, so as to observe the heart, and to insulate the pneumogastric nerves which are expended in its tissue, we prove that so long as these nerves are not acted upon, the heart continues to beat as in ordinary, and as soon as they are excited by a powerful electric current, the diastole of the heart is arrested, that is to say, relaxation takes place.

Fig. 14 is a tracing which shows the beginning of repose of the heart of a frog,* when its pneumogastric nerve is excited by electricity.

Fig. 15 is another tracing showing the entrance towards the contraction of the muscle on the limb of the frog, when the nerve which is expended upon it is excited successively and alternately.

* The paralysing influence of the pneumogastric upon the beatings of the heart, is not perfectly expressed in the frog. We here exhibit a tracing obtained under the same conditions, by Mr. Marey, with the heart of a horse, and which very nearly declares an almost absolute arrest of the heart under the influence of the irritation of the pneumogastric nerve. But it is understood, that at the conference in the amphitheatre of the Sorbonne, it was impossible to make the experiment upon a horse.

Repose of the pneumogastric contraction of the heart. Excitation of the nerve: repose of the heart.

FIG. 14.—Tracing representing the beatings of the heart of a horse, to show the paralysing influence of the irritation of the pneumogastric nerve on the contractions of the heart.

Repose of the nerve: repose of the muscles. Excitation of the nerve: contraction of the muscles.

FIG. 15.—Tracings representing the contractions of the muscles of the foot of a frog, to show that the irritation of the nerves provokes these contractions.

The result is equally general; it is produced in all vertebrated animals, from the frog to man. It will be

necessary, then, to have the fact of this singular and paradoxical influence of the nerves on the heart always before our minds, because it is this result, which will serve us as a starting point, in explaining hereafter, how the central organ of the circulation can react on our perceptions.

But before considering this point, it is necessary to examine more closely the various forms which the stoppage of the heart presents under the influence of the galvanic excitement of the nerves. The excitation of the pneumogastric nerves, or the nerves of the heart, by a very active electric current, soon arrests the beatings of that organ. However, there are always some varieties in the phenomena which depend upon the sensitiveness of the animal. If very sensitive mammifers be acted upon, the heart is instantly arrested, whilst in cold-blooded animals, and especially in the winter, the heart does not immediately feel the nervous influence; many pulsations may still take place before it is arrested. After the cessation of violent galvanic excitation of the nerves, the pulsations no longer appear; the arrest of the heart is then definite, and death immediately takes place.

Galvanic excitation of the pneumogastric nerves, arrests the heart so much the more energetically, as the application is more sudden, and if it has been seldom repeated. When the excitation is repeated many times, or when it has been continued for a long time, the sensibility of the heart and nerves are blunted to such a degree that electricity loses its power to arrest its pulsations; the same takes place when the nerves are gradually irritated; very violent currents may thus be successively employed without causing arrest of the heart's

action. When feeble excitations are applied to the nerves of the heart, the results, in the main, are always the same; only, the difference of intensity gives them another appearance. Indeed, feeble and instantaneous galvanic excitation of the pneumogastrics, in a healthy and very sensitive animal, produces a sudden arrest of the heart; but this arrest is of so short duration, that it would often be imperceptible to an unsuspecting observer. Besides, after these light or moderate actions, the cardiac pulsations soon reappear, with more energy and rapidity. It is thus seen that the energetic excitation of the nerves of the heart, brings on a prolonged arrest of that organ, with a return of its beatings more or less difficult and slow, whilst the moderate actions only provoke a very fleeting arrest of the heart's action, immediately followed by an acceleration in the pulsations, with an increase of the energy of the ventricular contractions.

All of the results which we have mentioned, whether relating to the excitation of the nerves which are distributed to the muscles of the limbs, or to the excitation of the nerves of the heart, have been furnished by experiments of vivisection, in which the excitant was applied to the motor nerves themselves. But in the natural state, things do not go on in this way: there are physiological excitants which irritate the motor nerves so as to determine their reaction on the muscles. These physiological excitants are two in number, the WILL and SENSATION, or sensibility. The will cannot exercise its influence on all of the motor nerves of the body; the nerves of the heart, for example, are beyond its influence. Sensation, on the contrary, exercises an influence which is general; and all of the motor nerves, be they

voluntary or involuntary, submit to its reflex action. All sensitive actions, which react on the motor nerves, and give rise to involuntary movements, are called *reflex*; because it is supposed that the sensitive impression, coming from the periphery, is reflected at the nervous center upon the motor nerve.

It will be useless to extend our remarks any farther on the mechanism of reflex nervous actions, which, at this day, forms one of the most important bases of the physiology of the nervous system. It will suffice us to know, that all involuntary movements are the result of the simple action of sensation, or of the sensitive nerve upon the motor nerve, which then reacts on the muscle. All of the involuntary movements of the heart that we shall have to observe, have no other origin than the reaction of sensation on the motor pneumogastric nerves of that organ; and when we say, for example, that a painful impression arrests the movements of the heart, we simply signify that a sensitive nerve, primitively excited, has transmitted its impressions to the heart by exciting the pneumogastric, which, in its turn, has caused its motor influence to be felt by the heart, absolutely, as when we act in our experiments with the galvanic current. When the physiologist provokes a motor nerve to react on the muscles by means of a galvanic current, or by pinching, he substitutes an artificial for a natural excitant, which is the will, or the sensibility; but the results of the nervous motor action are always the same. It will soon be seen, that all of the forms of arrest of the heart's action which we have observed, by acting directly with the galvanic agent on the pneumogastric, reproduce themselves, in consequence of various sensitive influences. As we now

know that sensitive influences can act on the heart, by exciting its motor nerves, we can then understand that intermedium of language, and when we say: that the sensibility, or the sentiments, react on the heart, you will know what that signifies, physiologically.

Our direct experiments on the excitation of the pneumogastric nerves, have shown us, that the more sensitive the animal is, so much the more prompt is the heart in receiving nervous impressions, and to be arrested in its actions; it is the same for the reactions of the sensitive nerves on the heart. In the frog the heart is not arrested by pinching the skin: more energetic means are necessary to produce this effect; but in animals higher in the scale—in certain races of dogs, for example—the slightest excitations of the sensitive nerves show their effect upon the heart. If a hœmamometer be placed on the artery of one of these animals, so as to have the expression of the pulsations under our eyes, by the oscillation of the mercurial column, we will observe, at the moment when a sensitive nerve is rapidly excited, that there is a stoppage in the diastole of the heart; this brings about a suspension of the oscillation, with a slight lowering of the mercurial column. Soon afterwards, the pulsations reappear, considerably accelerated, and more energetic; for the mercury is raised, sometimes many centimetres, to return to its primitive point; when the heart becomes calm, and resumes its natural rythm. The heart is sometimes so sensitive in certain animals, that very slight excitations of the sensitive nerves may bring on reactions, even when the animal manifests no sign of pain. These are some of the experiments performed by my master, Magendie, and my-

self, many years ago, and which have been often repeated and verified by various processes.

In proportion as the animal is elevated in the scale of organization, the heart becomes a more and more delicate reagent, to convey the sensitive impressions which take place in the body; and it is natural to think that man, in this connection, should hold the first rank. In him the heart is not only the central organ of the circulation of the blood, but it becomes also a center where all of the sensitive nervous actions expend themselves. The nervous influences which react on the heart, come either from the periphery by the cerebro-spinal system, or from the internal organs by the great sympathetic, or from the cerebral center itself; for in a physiological point of view, the brain should be considered as the most delicate of all the nervous surfaces: whence it results, that the sensitive actions which are derived from this source, are those which exercise the most energetic influence over the heart.

How is it possible to conceive of the physiological mechanism, by the aid of which, the heart is connected with the manifestation of our sentiments? We know that this organ can receive the *contre coup* of all the sensitive vibrations which take place in us: and that sometimes, if the impression has been very strong, there results from it a violent arrest, with momentary suspension and feebleness of the circulation: if the impression has been slight or moderate, a slight arrest, with reaction and increase in the number and the energy of the cardiac pulsations. But how, then, can this state translate our sentiments? This is the question which needs an explanation.

Let us remember that the heart never ceases to be a

forcing pump; that is to say, a motive power, which distributes the blood to all of the organs of the body. If it stops, there is necessarily a suspension or diminution in the supply of the vital liquid to the organs, and as a consequence, suspension or decrease in their functions. If, on the other hand, the slight arrest of the heart's action is followed by an increased intensity in its action, a large quantity of blood is distributed to the organs, and as a consequence, there is an exaggeration of their functions. However, all of the organs of the body, and all of the organic tissues, are not equally sensitive to these variations of the arterial circulation, which may quickly diminish or increase the quantity of the nutritious liquid which they receive. The nervous organs, and above all, the brain, which constitutes the apparatus whose texture is the most delicate, and the superior of all in the physiological order, receives the first *contre coup* of these circulatory disturbances. It is a general law for all animals, from the frog to man; that suspension of the circulation of the blood, in the first place, brings about loss of the cerebral and nervous functions, in the same way, as an exaggeration of the circulation exalts the central and nervous manifestations.

Nevertheless, these reactions of a modified circulation on the nervous organs demand very different periods, according to the species; the time it takes to affect cold-blooded animals, is very long, especially in the winter; a frog remains several hours before he experiences the consequences of the arrest of the circulation; the heart may be taken from it, and for four or five hours after, it continues to jump and swim, without appearing to have had either its will or its movements disturbed in the slightest degree. In warm-blooded animals it is alto-

gether different; cessation of the heart's action causes the cerebral phenomena to disappear very rapidly, and this takes place much more easily, as the animal is high in the scale of organization; that is to say, as it possesses a more delicate nervous organization. Reason and experiment show us that in this respect man ought to hold the first rank; his brain is so delicate that he will experience, in a few seconds, almost instantaneously, the reverberation of the nervous influences exercised on the central organ of the circulation; influences which, you will soon see, translate themselves sometimes by an emotion, and sometimes by syncope. Physiological phenomena everywhere pursue one identical law in all animals; but the more or less delicate nature of the living organism gives them an entirely different expression; thus the law of the reaction of the heart on the brain, is the same in the frog and in the man; the frog, however, can never experience an emotion or a syncope, because the time necessary for its heart to feel the nervous influence, and its brain to experience the circulatory impulse, is so long, that the physiological relation between the two disappear. In man, the influence of the heart on the brain is translated by two principal conditions, between which many intermediate ones may be supposed: these are *syncope* and *emotion*.

Syncope is due to a momentary cessation of the cerebral functions, in consequence of an interruption in the supply of arterial blood to the brain. Syncope may be produced by tying, or directly compressing all of the arteries which go to the brain; but we will occupy ourselves at this time only with syncope which occurs in consequence of a sensitive influence carried to the heart, and energetic enough to arrest its beatings. The arrest

of the heart's action which produces loss of consciousness, by depriving the brain of blood, also brings about pallor of the countenance, and a crowd of other accessory effects, which have nothing to do with the question now under consideration. All energetic and sudden sensitive impressions, whatever else may be their nature, may bring on syncope. Physical impressions on the sensitive nerves, moral impressions, or painful and voluptuous sensations, conduce to the same result, and bring on the arrest of the heart's action. The duration of syncope is naturally connected with the duration of the stoppage of the heart. The more intense the arrest has been, the longer, in general, will the syncope last: and the more difficult will it be to re-establish the cardiac pulsations, which at first, return irregularly, and but slowly resume their normal rythm. Sometimes the arrest of the heart is final, and the syncope is mortal—this may take place in very feeble, and at the same time very sensitive, individuals. It has been proved, experimentally, that at times, it is only necessary to produce an acute pain, by pinching a sensitive nerve, to bring about a definite arrest of the heart, and mortal syncope in doves, wasted by starvation.

Emotion arises from the same physiological mechanism as syncope, but it has an entirely different manifestation. Syncope, which takes the blood from the brain, gives a negative expression, proving that a violent nervous impression has gone to reflect itself on the heart, to rebound on the brain. Emotion, on the contrary, sends to the brain a more active circulation, and gives a positive expression; in this sense the cerebral organ receives a functional superexcitement, in harmony with the nature of the nervous

influence which has brought it on. In emotion, there is always an initial impression, which in some way surprises, and very slightly arrests, the heart's action, and consequently excites a feeble cerebral shock, producing a fleeting pallor of the countenance; the heart, like an animal pricked by a spur, soon reacts, quickens its pace, and sends the blood in full tide through the aorta, and all the other arteries. The brain, the most sensitive of all of the organs, immediately, and before all of the others, feels the effect of this modification of the circulation. The brain is doubtless the starting point of the nervous sensitive impression; but by the reflex action on the motor nerves of the heart, the sensitive influence has provoked the conditions in the brain which are connected to the manifestation of sentiment. The heart is no more the seat of our sentiments than the hand is the seat of our will; but the heart is an instrument which concurs in the expression of our sentiments, as the hand concurs in the dictate of the will.

In fine, the heart of man is the most sensitive of all the organs of vegetative life; it is the first to receive the cerebral nervous influence. The brain is the most sensitive of the organs of animal life: it receives the first fruits of the circulation of the blood. The result is, that these two culminating organs of the living machine are connected in ceaseless action and reaction. The heart and brain are, then, in solidarity of reciprocal actions of the most intimate character; actions which increase and decrease in proportion as the organism becomes more delicate and more developed. These connections may be constant or fleeting, varying with the sex and age of the animal. It is thus, that at the period of puberty, when the organs, until then imperfect and

inert, are awakened and developed, giving birth to sentiments in the brain, until now unknown, and bearing to the heart new impressions. The sentiments we experience are always accompanied by reflex actions of the heart; it is from this organ that the condition necessary for the manifestation of sentiments proceeds, although the brain may be their exclusive seat. In the more elevated organisms, life is but a continual exchange between the sanguineous and nervous systems. The expression of our sentiments is made by an exchange between the heart and the brain, the two most perfect wheels of the living machine. This exchange is carried on by well known anatomical mechanism; by the pneumogastric nerves, which transmit the nervous influence to the heart: and by the carotid and vertebral arteries, which convey the blood to the brain (Fig. 16). The whole of this wonderful mechanism depends, then, upon a thread, and if the nerves which unite the heart to the brain should be destroyed, this reciprocity of action would be interrupted, and the manifestation of our sentiments very seriously disturbed.

All of these explanations, I may be told, bear the impress of materialism. To that I will reply, that it is not the question under consideration. If it did not take me too far from our inquiries, I could easily show you, that in physiology, materialism leads to nothing, and proves nothing; but I will ask: is a concert of musical instruments less ravishing, because the philosopher calculates mathematically all of its vibrations? Is a physiological phenomenon less wonderful because the physiologist has analysed all of its material conditions? It is very necessary, then, that these analyses should be made, that these calculations should be pursued, for without them

there would be no science. Then physiological science teaches us that onthe one side, the brain really recei ves the impression of all of our sentiments, and on the

FIG. 16.—The anatomical connections of the heart with the brain, by the carotid arteries and the pneumogastric nerves, to explain the reactions of these two organs upon each other.

C. The heart. *a.* The carotid artery going to the brain. *n.* Pneumogastric nerve, the branches of which are distributed to the heart.

other side, that the heart reacts by sending to the brain the necessary conditions for the manifestation of these

sentiments. Hence it results that the poet, and the man of romance, appeal to our hearts to affect us, that the man of the world, expressing his sentiments at the same time by calling upon his heart, uses metaphors which correspond to physiological realities. Sometimes a word, a *souvenir* the sight of a passing occurrence, awaken in us a deep and intense suffering: this word, this memory, may not be painful in themselves, but are so only in the phenomenon they excite. When any one says that his *heart is broken* with grief, real phenomena are produced in the heart—its action has been arrested—if the painful impression has been too sudden, the blood does not reach the brain—syncope and nervous crises are the consequence. There is, then, good reason, when any one has terrible news to impart, which could cause great mental distress, why it should be conveyed with the utmost caution.

By our experiments on the nerves of the heart, we know that excitants gradually applied to the heart, blunt or decrease the sensibility of that organ, without producing arrest of its pulsations.

When any one says that he has *a full heart*, after having suffered agony for a long time, or having experienced painful emotions, this also responds to particular physiological conditions of that organ; prolonged painful impressions, become incapable of arresting the heart's action; they fatigue and wear it out, retarding its pulsations, prolonging its diastole, and producing in the precordial region a sense of fulness or contraction.

Agreeable impressions also correspond to particular states of the heart. When a female is surprised by a pleasant emotion, the words which have given it birth have flashed through the mind like lightning, without

stopping there; the heart has been momentarily attacked in advance of all reasoning or reflection. Sentiment begins to manifest itself after a slight arrest of the heart, which may be imperceptible to all save the physiologist; the heart, pierced by a nervous impression, reacts in palpitations, which cause it to bound and beat more violently against the breast, at the same time that it sends the blood to the brain, whence results the blush of the face, and the peculiar expression of the features, expressive of pleasure. To say that love *causes the heart to palpitate*, is not only a poetic form of speech, it is also a physiological reality. When any one says that he loves with *all of his heart*, this physiologically signifies that somebody's presence, or his memory, awakens a nervous impression, which, transmitted to the heart by the pneumogastric nerves, causes that organ to react in a way most conducive to arouse in the brain a sentiment or emotion of affection. I suppose, be it well understood, that the avowal is sincere: without this, the heart will not be affected, and the sentiment would only be lip-service.

When it is said that great thoughts spring from the heart, it is equivalent to saying that great thoughts come from sentiment, for our sentiments, which have their physiological starting point in the nervous centers, act on the heart as peripheric sensations. The brain of man should have the heart at its service to express its sentiments. Two hearts united, are hearts which beat in unison under the influence of the same nervous impressions; hence result the harmonic expression of similar sentiments.

Philosophers say that one can *master his heart* and *silence his passions*. These are expressions which physi-

ology can interpret: It is known that, by the power of will, man may control many of the reflex actions due to sensations produced by physical causes. Reason, without doubt, exercises the same empire over the moral sentiments. Man may, then, become able, through the power of reason, to prevent certain reflex actions from being effected upon the heart: but the greater the triumph of pure reason, the weaker will sentiment become.

The nervous power capable of arresting reflex actions in general, is less in woman than it is in man: it is this which has given her the supremacy in the domain of physical and moral sensibility; it is this which has celebrated her as having a heart more tender than that of man.

But I must bring these considerations, which would involve too much time, to a close, by a general conclusion.

Science does not contradict the observations and data of art, and I cannot subscribe to the opinion of those who believe that the positive character of science must prove fatal to inspiration. According to my views, I am obliged to come to another and contrary conclusion. The artist may find in science the most solid foundations, and the savant may draw from art the most assured intuition. Science, although advanced, is still very imperfect, and critical periods may arise, which harrass and disturb, rather than aid the artist. This may be the case with physiology, at the present time, as respects the poet and the philosopher. This is but a transitory state, and I am convinced, that when physiology shall be sufficiently advanced, the poet, the philosopher and the physiologist will understand each other.